Evaluating remote sensing approaches to describe forest canopy structure for ladder fuel estimation to predict wildfire burn severity

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PRESENTED AT:

INTRODUCTION

While fire is an important ecological process in the western United States, wildfire size and severity have increased over recent decades as a result of climate change, historical fire suppression, and lack of adequate fuels management. Due to the urgency to build ecosystem resilience and protect life and property, land managers implement fuel management programs. Technology used to quantify ladder fuels, which bridge the gap between the surface and canopy, and lead to more severe canopy fires, can inform management treatments to reduce future wildfire risk.

METHODS

In this study, we evaluated several remote sensing techniques and field measurements to quantify ladder fuels and related ladder fuel metrics to wildfire burn severity. Ladder fuel data at 1-m strata from 1-8 m were collected using a photo banner, a terrestrial laser scanner (TLS), a handheld-mobile laser scanner (HMLS), an unoccupied aerial system (UAS) with a multispectral camera and Structure from Motion (SfM) processing (UAS-SfM), and an airborne laser scanner (ALS) in 35 plots in oak woodlands in Sonoma County, California, USA prior to the occurrence of natural wildfires. Canopy base height (CBH) was estimated in the field, and post-wildfire burn severity was calculated using the Relativized delta Normalized Burn Ratio (RdNBR). The linear relationships between ladder fuel metrics at each stratum collected via different methods were compared using Pearson’s correlation (r) and RdNBR prediction via ladder fuel estimation was evaluated with a generalized linear model (GLM).

FIGURES AND TABLES

Figure 1: Map of our study locations (Pepperwood Preserve and Saddle Mountain Open Space Preserve) and plots (indicated by grey squares and circles) in Sonoma County, California. The perimeter of each wildfire that occurred during our research study is shown in red.

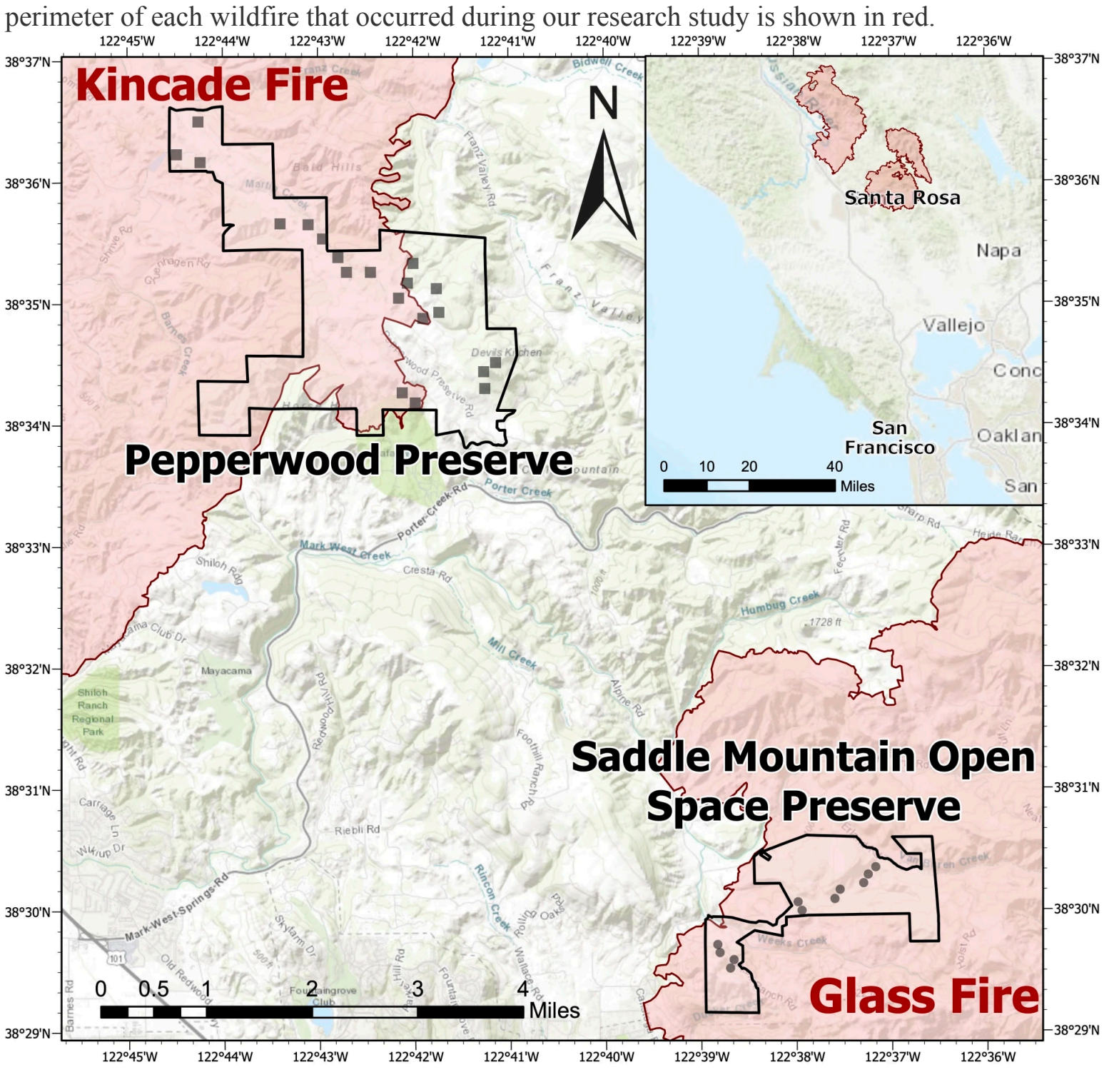

Figure 2: Vertical profile of vegetation (VVP) generated by each remote sensing method, separated into bins based on CBH for a representative plot. The percentage of points at each height was found by dividing the number of points at each height by the total number of points (above 0.5m) for each method. VVP under 8m shows the same data as the whole VVP, but zoomed in. The grey dashed line shown in the VVP represents 8m, the maximum height we used for ladder fuels, the grey dashed lines shown in the VVP under 8m, are in 1m increments and represent our ladder fuel strata.

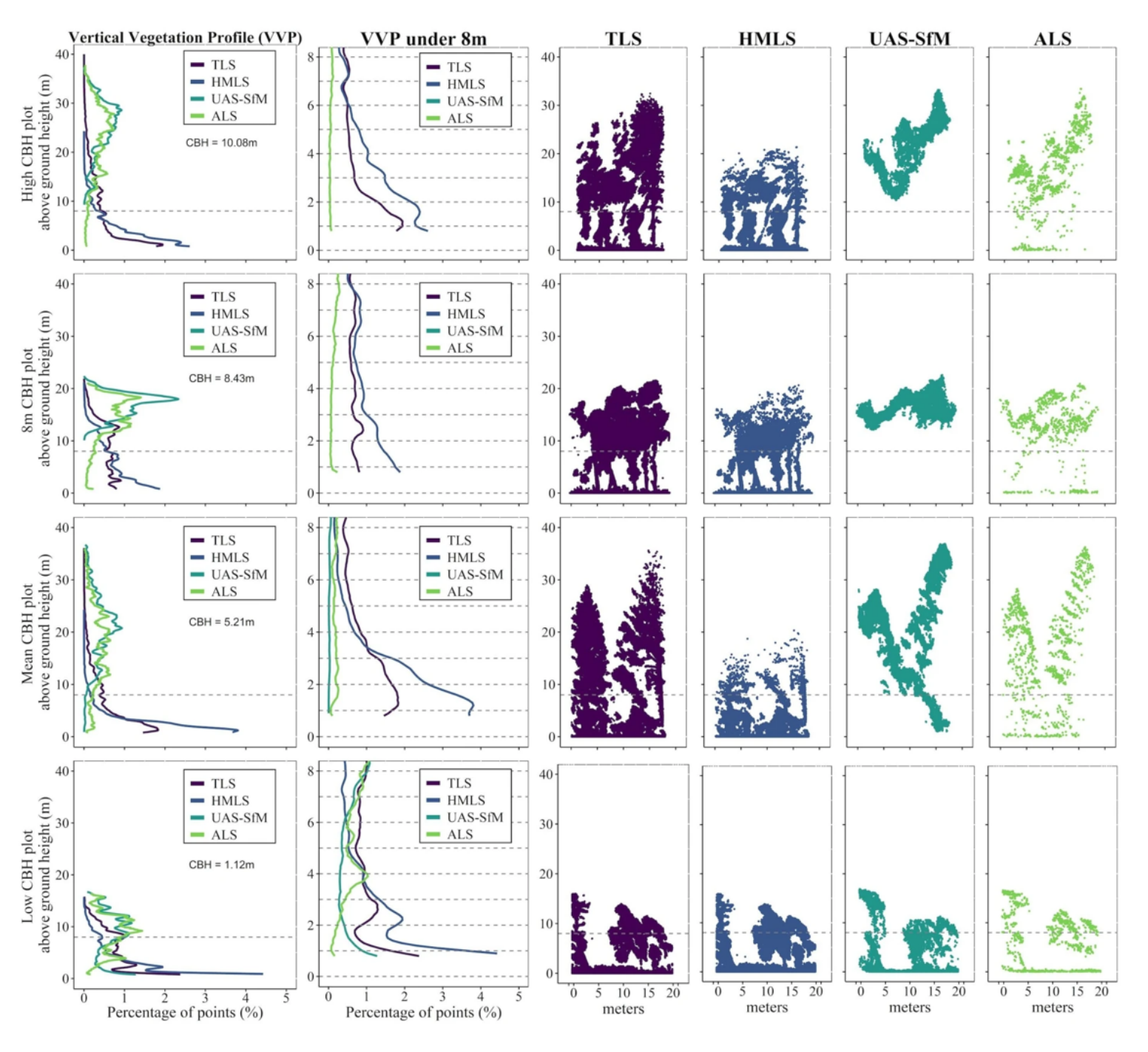

Figure 3: Heatmap of Pearson correlation coefficients to compare ladder fuel metrics at multiple strata across methods. Significance is as follows: *** p-value ≤ 0.001, ** 0.001 > p-value ≤ 0.01, * 0.01 > p-value ≤ 0.05. Note the removal of the banner from strata above 4 m.

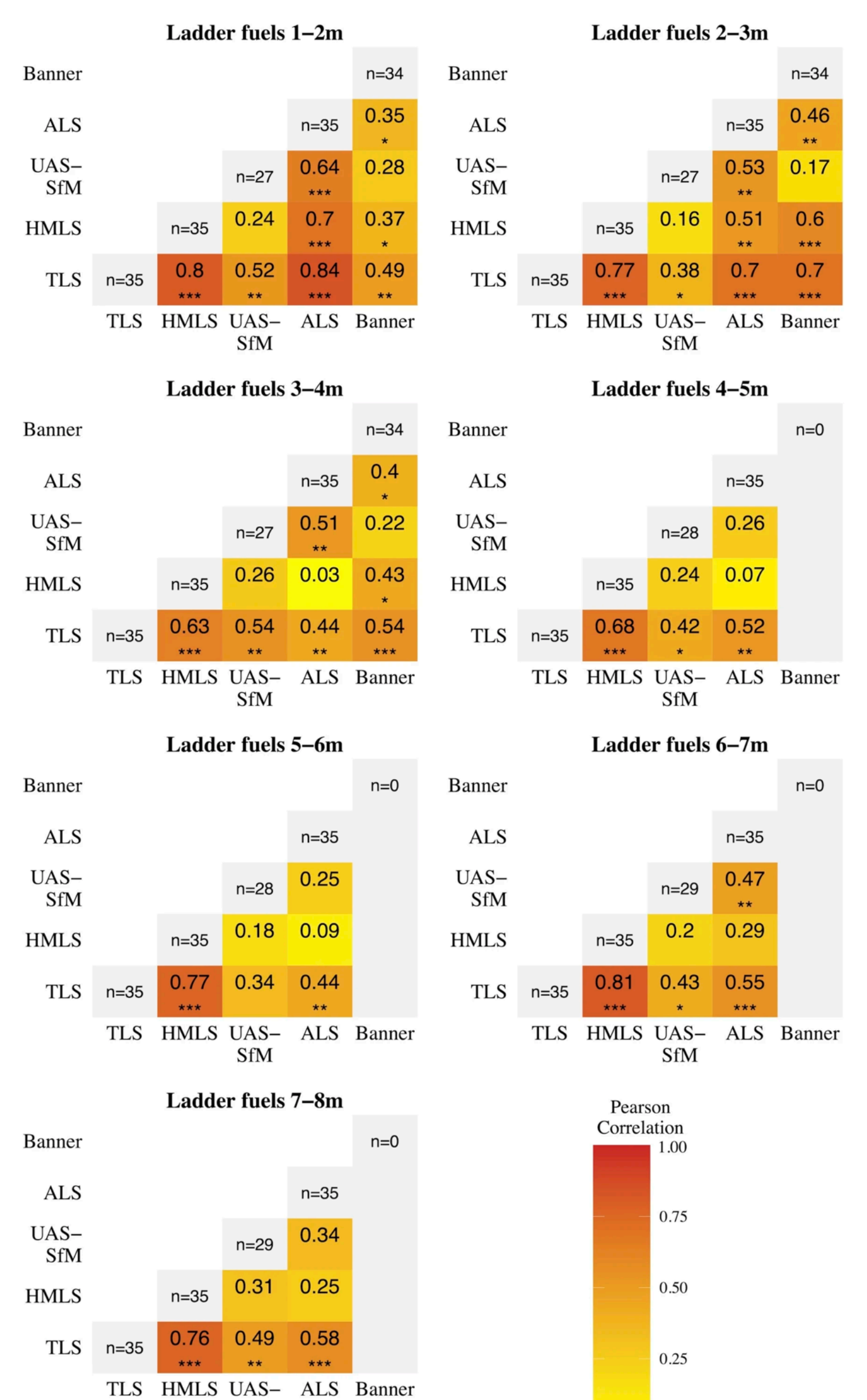

Figure 4: Heatmap of Pearson correlation coefficients to compare only the ladder fuel metric at 1-2 m by CBH category across all methods. Significance is as follows: *** p-value ≤ 0.001, ** 0.001 > p-value ≤ 0.01, * 0.01 > p-value ≤ 0.05. Note the removal of UAS-SfM from the very high CBH due to low sample size (n=2).

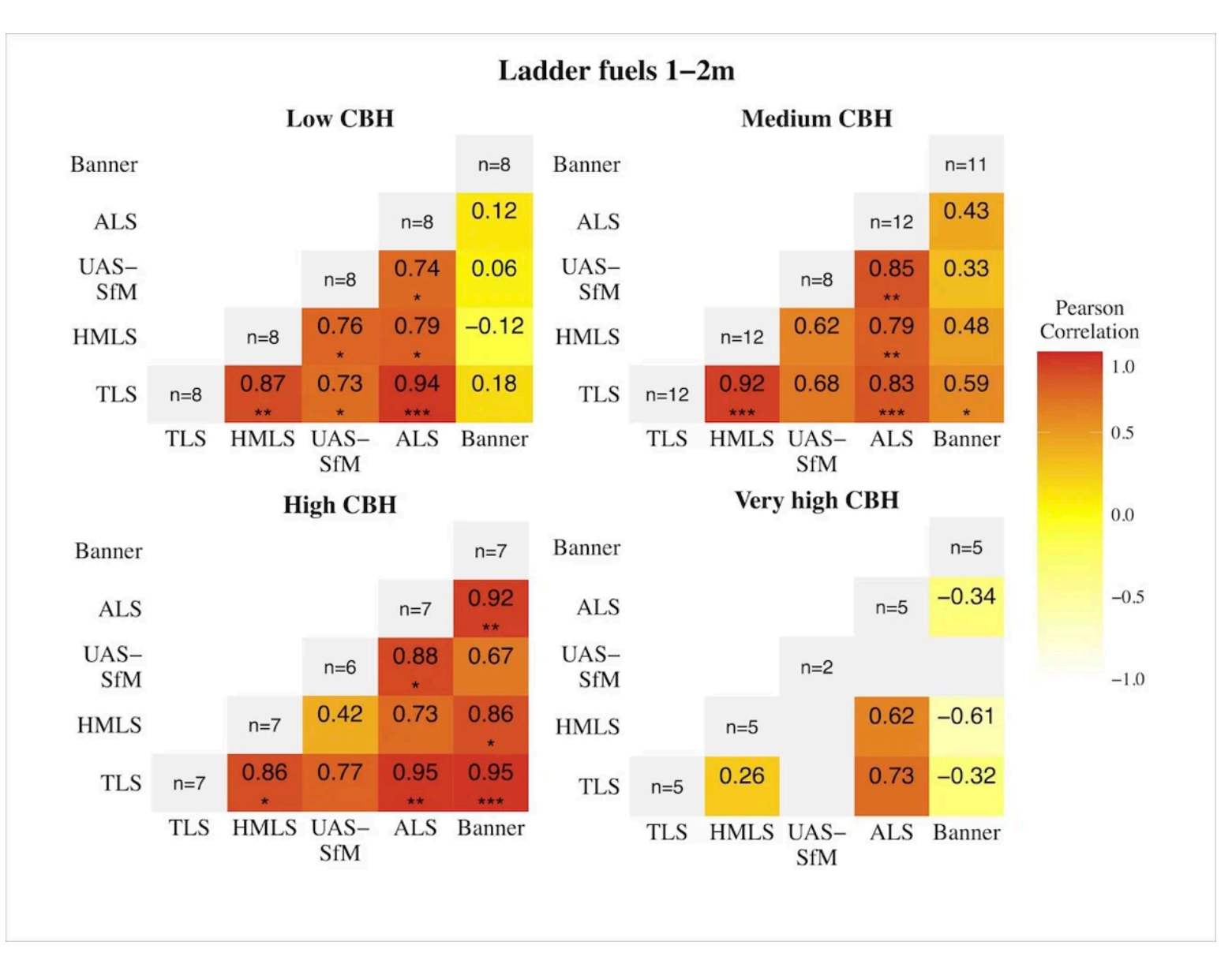

Figure 5: Heatmap of Pearson correlation coefficients to compare ladder fuel metrics 1-4 m and 1-8 m across methods. Significance is as follows: *** p-value ≤ 0.001, ** 0.001 > p-value ≤ 0.01, * 0.01 > p-value ≤ 0.05.

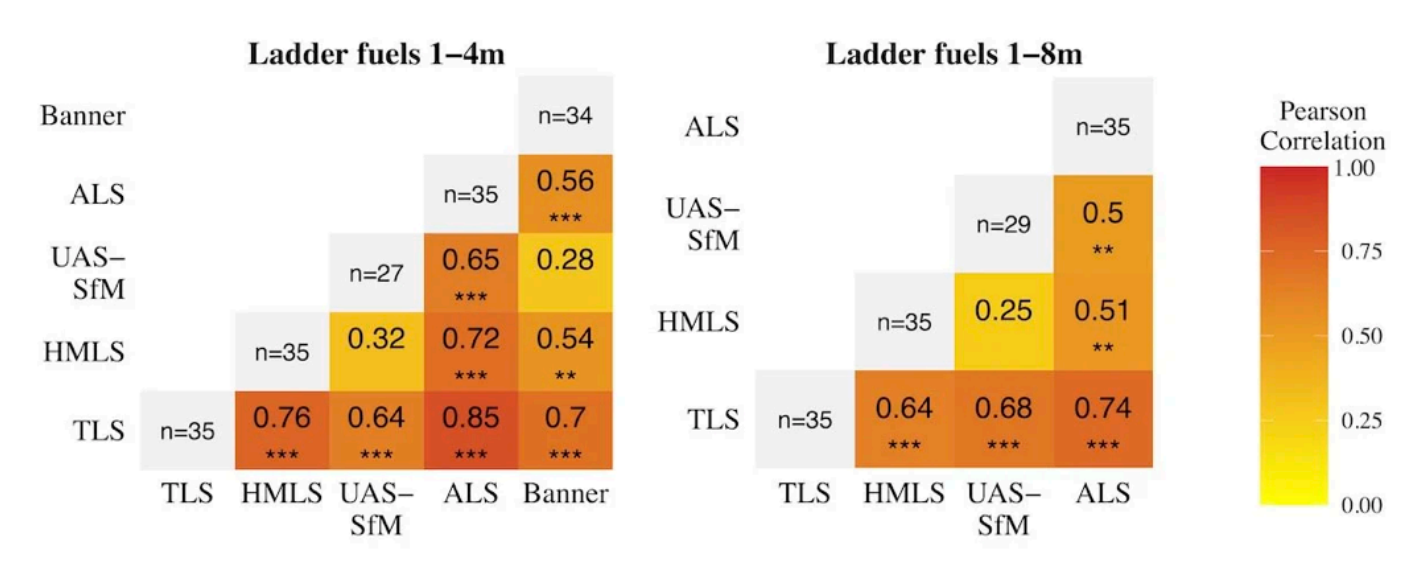

Figure 6: Heatmap of Pearson correlation coefficients for ladder fuel metric 1-4 m by CBH category across all methods. Significance is as follows: *** p-value ≤ 0.001, ** 0.001 > p-value ≤ 0.01, * 0.01 > p-value ≤ 0.05.

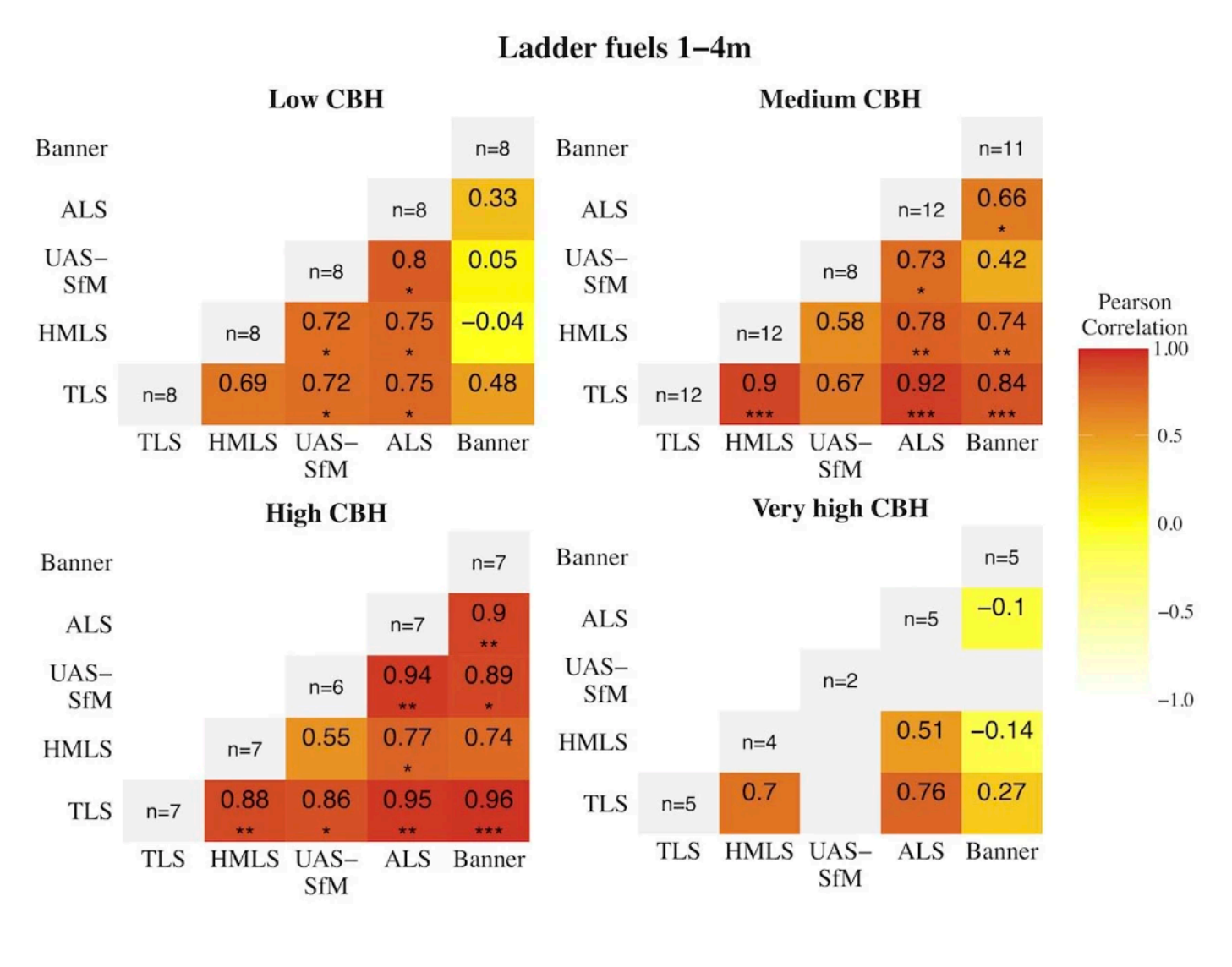

Table 1: Ladder fuel metric calculations.

Ladder fuel strata	# points in strata	# points in and below strata
1-2m	sum(Z > 1 & Z <= 2)	sum(Z >= 0 & Z <= 2)
2-3m	sum(Z > 2 & Z <= 3)	sum(Z >= 0 & Z <= 3)
3-4m	sum(Z > 3 & Z <= 4)	sum(Z >= 0 & Z <= 4)
4-5m	sum(Z > 4 & Z <= 5)	sum(Z >= 0 & Z <= 5)
5-6m	sum(Z > 5 & Z <= 6)	sum(Z >= 0 & Z <= 6)
6-7m	sum(Z > 6 & Z <= 7)	sum(Z >= 0 & Z <= 7)
7-8m	sum(Z > 7 & Z <= 8)	sum(Z >= 0 & Z <= 8)

Table 2: Point density at each stratum, for each method. We included 0-1m because this data is included in the ladder fuel strata and clearly demonstrates the significant amount of data points for both the TLS and HMLS data. Point density was calculated by rasterizing the stratum. The percentage of points at each stratum was found by dividing the number of points at each stratum by the total number of points for each method.

	TLS	HMLS	UAS-SfM	ALS
0-1m	173,788.3	10,201.52	31.74	3.20
1-2m	57,311.12	2,884.81	10.55	1.70
2-3m	61,264.81	2,088.40	10.40	1.97
3-4m	47,787.23	1,364.58	11.89	2.10
4-5m	36,910.99	899.64	11.33	2.18
5-6m	31,782.90	672.06	15.25	2.32
6-7m	27,585.26	514.63	21.13	2.31
7-8m	22,966.50	380.56	24.78	2.50

Table 3: Percentage of points at each stratum, for each method. We included 0-1m because this data is included in the ladder fuel strata and clearly demonstrates the significant amount of data points for both the TLS and HMLS data. The percentage of points at each stratum was found by dividing the number of points at each stratum by the total number of points for each method.

	TLS	HMLS	UAS-SfM	ALS
0-1m	43.5%	64.2%	14.9%	16.3%
1-2m	10.4%	13.0%	2.4%	1.1%
2-3m	7.7%	6.8%	1.2%	1.9%
3-4m	5.9%	4.2%	1.1%	2.3%
4-5m	4.8%	2.9%	1.2%	2.7%
5-6m	4.4%	2.3%	1.7%	3.2%
6-7m	4.0%	1.9%	2.5%	3.8%
7-8m	3.5%	1.4%	3.2%	4.6%
Total 1-8m	40.7%	32.5%	13.3%	19.6%
Total 0-8m	84.2%	96.7%	28.2%	35.9%

Table 4: GLM model results using RdNBR. The overall sample size for each method and the sample size broken down into burn severity categories (no change, low, moderate and above) are also shown.

	Model	R^2	SBC	Sample Size			
				Total	NC	Low	Moderate+
TLS	Int, 1-2m*CBH, CBH	0.67	255.4	25	3	13	9
HMLS	Int, 7-8*CBH	0.44	259.0	25	3	13	9
UAS-SfM	Int, 7-8, 3-4*CBH	0.53	174.0	17	3	9	5
ALS	Int, 1-2m*CBH, 3-4, 5-6*CBH	0.66	252.7	25	3	13	9
Banner	Int	0.00	251.2	24	3	12	9

RESULTS

All methods were not consistently related to each other, unless CBH class was included as a means of categorizing structural differences among plots. The UAS-SfM approach often could not produce measurements below 8 m due to lack of below-canopy detection, and, therefore, is highly limited for ladder fuels estimation in oak woodland and mixed conifer forests. The most common ladder fuels strata included in the burn severity model were 1-2 m and 3-4 m. The most predictive models included data from TLS and ALS with R2 of 0.67 and 0.66, respectively.

CONCLUSIONS

By accounting for interactions between ladder fuels, CBH, and burn severity, diverse remote sensing approaches can be used to estimate and validate ladder fuels. Remote sensing methods, which are generally advancing more rapidly than those of fire behavior modelling, present an opportunity to forge new pathways in forest fuel estimation.

AUTHOR INFORMATION

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ABSTRACT

Wildfires are becoming larger and more severe due to climate change and historical fire suppression. Technology to quantify ladder fuels, which bridge the gap between the surface and the canopy, can help manage forest structure to reduce fire hazard. In this study we evaluated several remote sensing techniques and field measurements to quantify ladder fuels and relate these metrics to burn severity. Ladder fuel data at 1-m strata from 1-8 m were collected using a 4 x 0.5-m photo banner, a terrestrial laser scanner (TLS), a handheld-mobile laser scanner (HMLS), an unoccupied aerial system with multispectral camera and Structure from Motion processing (UAS-SfM), and airborne laser scanner (ALS) data in 35 plots in oak woodlands and mixed-conifer forests in Sonoma County, California, USA, before wildfires occurred. Canopy base height (CBH) was also measured and post-wildfire burn severity was calculated using relativized delta normalized burn ratio (RdNBR). The linear relationships among ladder fuel metrics at each strata were compared and RdNBR prediction was evaluated with and without CBH as an interaction term. All approaches quantified ladder fuels across plots but were not consistently related to each other, unless CBH height class was included as a means of categorizing structural differences among plots. The UAS-SfM could not measure relative differences across plots due to lack of penetration to the ground. Ladder fuels between 1-2m and 2-3m best predicted RdNBR across most methods, where HMLS had the strongest correlation ($R^2 = +0.72$). By accounting for interactions between ladder fuels from 1-3 m, CBH, and burn severity, diverse remote sensing approaches can be used to estimate and validate ladder fuels. Importantly, forest structure has important implications for estimating ladder fuels and may be crucial to consider if ladder fuels are extrapolated across larger spatial scales.